PM Raman fiber laser at 1679 nm

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Abstract: We demonstrate a PM Raman fiber laser emitting light at 1679 nm. The laser has an slope efficiency of 67 % and an output power of more than 275 mW with a 27 pm linewidth.

OCIS codes: 140.3550 (Raman Lasers), 060.3510 (fiber lasers), 060.3735 (Fiber Bragg gratings).

1. Introduction

In the effort of extending the usable bandwidth of an optical communication system, there is a drive to move toward longer wavelength than the conventional 1.55 μm wavelength band [1]. Thulium amplifiers are obvious candidates for amplifiers providing gain at 2 μm. These amplifiers are being researched by various research groups for various applications [2, 3]. To bridge the gap between 1.55 μm and 2 μm, Raman amplifiers appear to be the most promising candidate. In this work we report on the efficiency of a Raman resonator emitting light at 1678 nm. This laser may be used as a pump source for a discrete Raman amplifier for signal wavelengths placed around 1800 nm.

When pushing the working wavelength of a Raman amplifier towards longer wavelengths, away from the minimum loss wavelength of an optical fiber at 1.55 μm, two parameters needs to be considered. First, the intrinsic fiber loss which increases dramatically with increasing wavelengths (see Fig. 1a) and second, the Raman gain coefficient which reduces with increasing wavelength, more specifically the Raman gain coefficient scales inversely with wavelength, when ignoring any wavelength effect on the effective area of the fiber. To investigate the impact of these drawbacks on a Raman laser we constructed a fiber laser based on the configuration in [4, 5]. As a result we demonstrate that in spite of the before mentioned drawbacks we were able to achieve a Raman resonator with a slope efficiency of 67 % and a threshold power of 850 mW, and we produced an output power exceeding 270 mW. We also demonstrate a slightly modified laser design resulting in a much lower threshold of 250 mW providing an output power of around 300 mW. Assuming a loss of 0.6 dB/km and a Raman gain coefficient of 2.66 $(\mathrm{Wkm})^{-1}$ scaled to 1810 nm a Raman gain of 9 dB is predicted.

2. Experimental setup and results

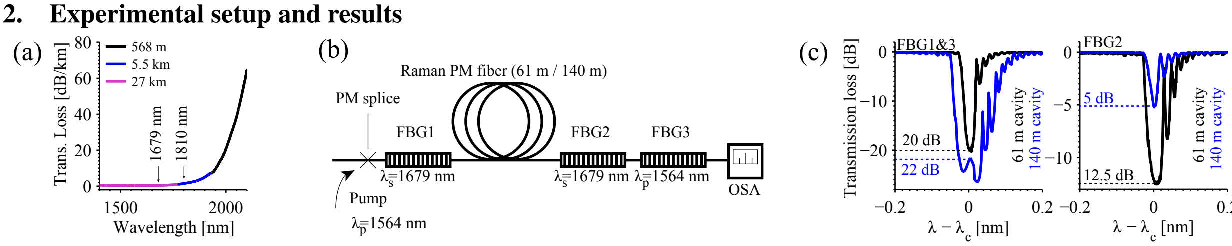

Fig. 1: (a) Measured transmission loss of a OFS True Wave fiber. (b) Experimental setup of the all PM fiber laser. (c) Spectral shape of the fiber Bragg gratings. It is noted that the illustrated FBG's are spectra measured individually during the FBG manufacturing process, which was performed at a grating wavelength of λ_c=1564 nm.

The all polarization maintaining (PM) experimental setup of the Raman fiber laser (RFL) is shown in Fig. 1b. In the setup the pump is launched into the RFL through an isolator. This prevents back-reflected pump power from going back into the pump laser. The cavity contains two fiber Bragg gratings (FBGs) FBG1&2 at 1679 nm, and a pump reflector grating, FBG3, at 1564 nm. The gratings are written directly in a PM Raman fiber, to avoid excess splice-losses.

We constructed two laser cavities, one being 61 m long and another one being 140 m long, both using a PM Raman fiber provided by OFS Fitel Denmark. The fiber had a transmission loss of 0.42/0.46 dB/km at the pump/signal wavelength and a Raman gain coefficient $g_R = 2.66(Wkm)^{-1}$ at the pump wavelength. The wavelength of the FBGs is fine-tuned using an active feedback temperature control system ($12pm/^oC$), which also allows for temperature stabilization of the cavity (std. variation $= 0.015^oC$), resulting in a corresponding FBG wavelength stability of about 0.2 pm. The spectral shape of the written FBGs are depicted in Fig. 1c, with a grating reflectivity estimated based on the measured grating transmission loss. Both reflector gratings, FBG1&3, have a reflectivity R$\geq$ 99% for both cavity lengths. The gratings were written directly in the fiber with a 50 mm phase mask and a UV excimer laser at 248 nm. The signal output grating, FBG2, has a lower reflectivity R=94/68 % optimized to the L=61/140 m cavity, respectively, to account for the different round-trip gain and loss.

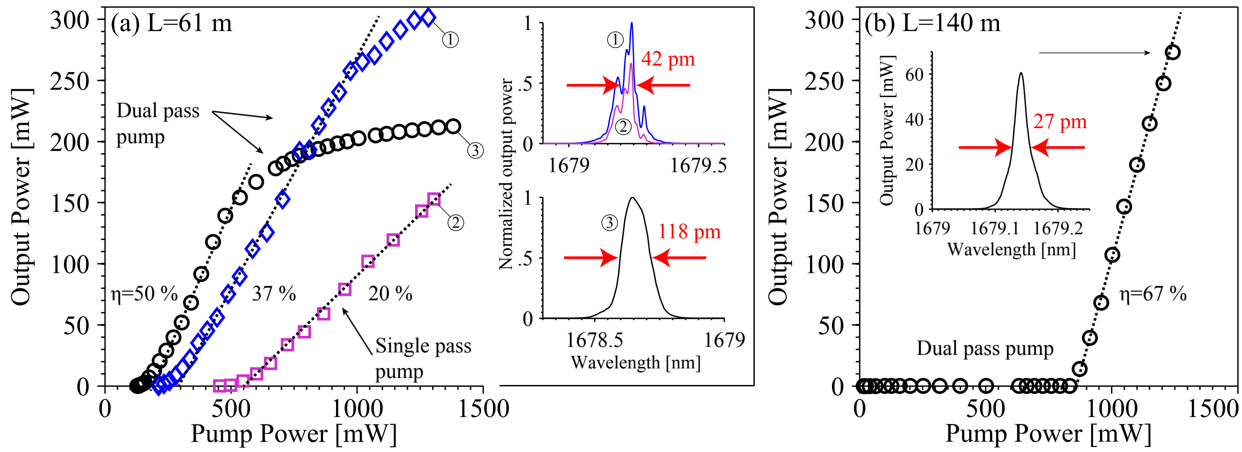

Fig. 2: Laser curve for the 61 m (a) and 140 m (b) cavity, inserts showing the spectral shape of the output at maximum pump power. The slope efficiency (η) and 3 dB linewidth ($\Delta\lambda$) is indicated.

The 61 m cavity (Fig. 2a) was lasing at 1679.24 nm, with a slope efficiency of 20 %. By recycling the pump using the pump grating (FBG3), a more efficient utilization of the pump resulted in a lower lasing threshold of about 250 mW, and an improved slope efficiency of 37 %. By decreasing the central wavelength of FBG2 by temperature tuning, the lasing wavelength was shifted to 1678.65 nm, also resulting in a lower lasing threshold of 180 mW and a slope efficiency of 50 %. Stimulated Brillouin scattering (SBS) caused a back-reflection of the injected pump, decreasing the efficiency of the laser, as observed in Fig. 2a at higher pump powers. The output linewidth (LW) is dependent on both the pump power and the exact lasing wavelength, and is displayed for the three laser curves at maximum output power (Fig. 2a).

A cavity length of 140 m was investigated, see Fig. 2b. Here, SBS free operation was obtained using two closely spaced pumps still within the FBG operation window, one at 1564.167 nm and one at 1564.184 nm. The LW of each pump laser was broadened using phase modulation. A lasing threshold of 850 mW, and a slope efficiency of 67 % with dual pass pump was found at a lasing wavelength of 1679.14 nm, along with a maximum output power of 273 mW. The spectral shape of the output reveals a 3 dB LW of 27 pm. Depending on the fiber length, grating reflectivity and associated optical intra cavity power, nonlinear effects such as SBS and four wave mixing (FWM), may influence the lasing signal. Depending on the RFL parameters, a LW between 20 to 200 pm (equals to 2.1 to 21 GHz) was observed. For the 61 m cavity containing higher intra cavity optical power, a LW surpassing the grating width was observed.

Since the pump power is quickly depleted in a RFL, a single pass configuration has been suggested [4]. We have investigated both a single- and double-pass pumped cavity of 61 m, results shown in Fig. 2a. The double-pass pump cavity has a more efficient pump utilization and thus allows for shorter cavity lengths, which consequently reduces both the cavity round-trip loss along with SBS.

3. Conclusion

A 61 m and a 140 m RFL has been demonstrated experimentally. Both RFLs utilize PM Raman fibers and optimized FBGs written directly within the fiber cavity. These RFLs are designed for an output wavelength close to 1680 nm. We have compared a single and a double pass pump configuration, and shown the advantages of using a double pass pump. The short RFL provides an output power exceeding 200 mW, a low threshold power of 200 mW and a slope efficiency of 50 %. An output power exceeding 275 mW was achieved using a longer double pump pass RFL, pumped simultaneously by two pump wavelengths. The length of the RFL was 140 m, and showed a slope efficiency of 67 %. By using two pump lasers SBS was completely avoided.

It is expected that further optimization of the gating parameters will lead to a further improved slope efficiency and an improved overall conversion efficiency of the short double-pass RFL.

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